Generating Importance Map for Geometry Splitting using Discrete Ordinates Code in Deep Shielding Problem

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1. Introduction

To design a radiation facility, radiation shielding calculation should be performed. Mostly, MCNP [1] code is used. When we use MCNP code for a deep shielding problem, we prefer to use variance reduction technique such as geometry splitting, or weight window, or source biasing to have relative error within reliable confidence interval.

To generate importance map for geometry splitting in MCNP calculation, we should know the track entering number and previous importance on each cells since a new importance is calculated based on these information.

If a problem is deep shielding problem such that we have zero tracks entering on a cell, we cannot generate new importance map. In this case, discrete ordinates code can provide information to generate importance map easily.

In this paper, we use AETIUS code as a discrete ordinates code. Importance map for MCNP is generated based on a zone average flux of AETIUS calculation. The results of MCNP with/without generated importance map are discussed.

2. Methods and Results

2.1 Discrete Ordinates Code

As a discrete ordinates code, we use AETIUS (An Easy modeling Transport code usIng Unstructured tetrahedral mesh, Shared memory parallel) code. This is programed using f90 and uses Gmsh [2] as a pre- and post- processing program. Before naming our code as AETIUS, it was tested on several applications [3,4]. MUST (Multi-group Unstructured geometry S_N Transport) is a twin code that programed with C++ [5,6]. The overall calculation flow of AETIUS is shown in Fig. 1.

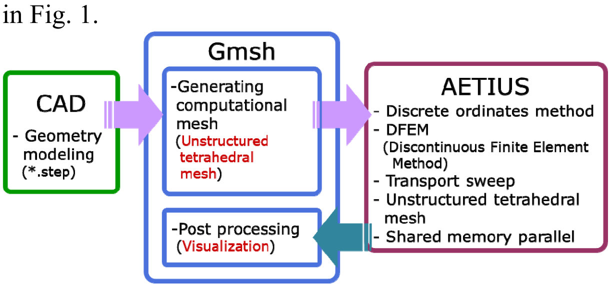

Fig. 1. The overall calculation flow of AETIUS.

2.2 Importance Calculation for Geometry Splitting

In the geometry splitting, the strategy to generate importance map is very simple. We increase importance proportional to the inverse ratio of the reduced number of particles between cell $i-1$ and i [7,8,9]. It is shown in Eq. (1).

$$NewIMP_i = \left(\frac{Particle\ Number_i}{Particle\ Number_{i-1}} \right)^{-1} NewIMP_{i-1}, \quad (1)$$

where i is index of cell, $i=1$ for cell with source, $i=I$ for cell with tally.

One example is shown in Fig. 2. Source is at the top and particle number is decreasing as passing though the cells from source cell to tally cell.

To have particle number in each cell, we multiply tracks and weight (inverse of importance) of the cell i since the tracks is the number of track with weight (inverse of importance) in the MCNP output.

	Tracks	IMP(weight)	Particle Number	New IMP
Source	300	1(1/1)	300×(1/1)	1
	200	2(1/2)	200×(1/2)	$3 = \left(\frac{200\times(1/2)}{300\times(1/1)}\right)^{-1} \times 1$
	100	4(1/4)	100×(1/4)	$12 = \left(\frac{100\times(1/4)}{200\times(1/2)}\right)^{-1} \times 3$
Tally	25	8(1/8)	25×(1/8)	$96 = \left(\frac{25\times(1/8)}{100\times(1/4)}\right)^{-1} \times 12$

Fig. 2. New importance calculation method in geometry splitting.

To generate importance map with AETIUS, we calculate total flux averaged over each cell and use it as particle number in Eq. (1).

2.3 Numerical Test

For a numerical test, we model a simple deep shielding problem as Fig. 3. A 1m×1m×1m cube is located at the center of origin (0,0,0) and filled with air. Concrete covers the outside of the cube. A point source is located at the origin (0,0,0) and the thickness of concrete block in the x-direction is 3m and 50cm for the other directions.

Three meter concrete block is divided into 30 concrete slabs in the x-direction to calculate zone average flux for generating importance map.

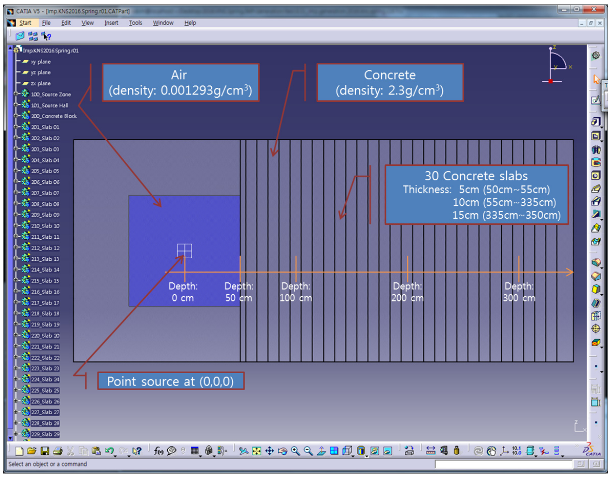

Fig. 3. Overview of the deep shielding problem.

We also prepared identical MCNP input as Fig. 4. Cell number begins from 201 to 230 and the importance map will be calculated on these cells.

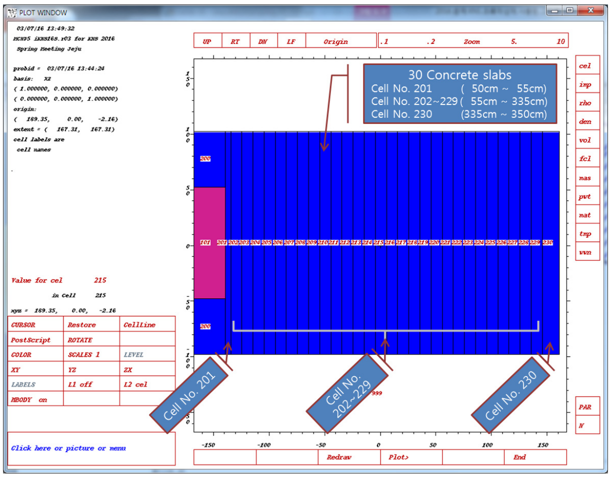

Fig. 4. The layout of 30 concrete slabs in MCNP modeling.

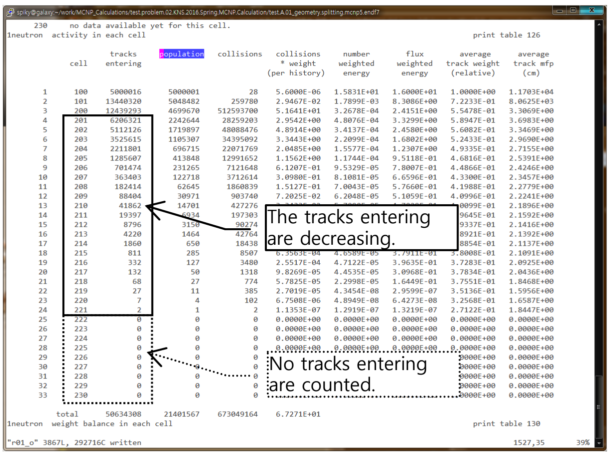

Fig. 5. The tracks entering result of MCNP calculation with imp=1 for all cells.

Output of MCNP calculation with imp=1 for all cells is shown in Fig. 5. As we can see, the tracks entering are decreasing as particles passing though the concrete slabs. Moreover, particles could not reach further than cell 222 (255cm<x<265cm).

Table I: Calculation parameters

	MCNP5	AETIUS	
		Fine calculation	Rough calculation
Source strength	Point source: 1 source particle/sec at origin (0,0,0)		
Source spectrum	Source is given in the 1st group of LANL-30		
Library	ENDF-B/VII.0		
Energy group structure	Continuous energy	LANL-30	
Material density	Air: 0.001293 g/cm^3 Concrete: 2.3 g/cm^3		
P_N order	n/a	3	
S_N order	n/a	Triangular Chebyshev-Legendre S_{40}	Level symmetric S_2
No. of element	n/a	34,935	6,543
Calc. time (sec)	n/a	18,664	51
Calc. options	with/without importance map	†FCS with point source	
Error criterion	nps:5×10^6	1×10^{-4}	
Parallel	MPI (50 cores)	OpenMP (120 cores)	

†FCS: first collision source method

We ran two AETIUS calculations. One is fine calculation for the reference result and the other is rough calculation for generating importance map.

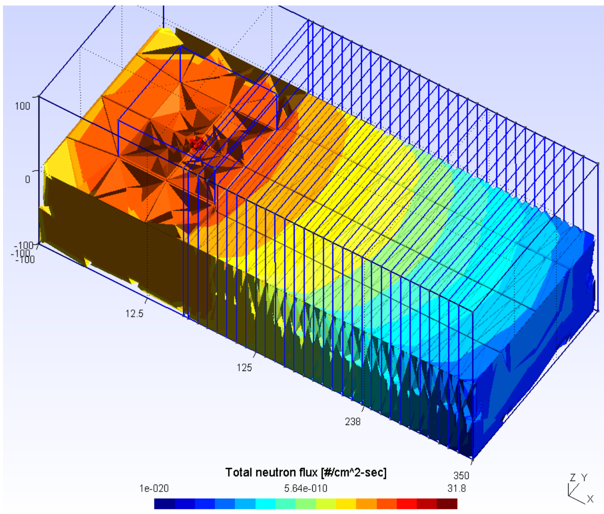

Fig. 6. Total neutron flux distribution of AETIUS rough calculation (S_2).

Importance map is a tool to send particles in the desired direction. As long as a rough calculation result is reasonable (no need to be exact), the importance map generated based on the rough calculation will be fine because the final calculation will be done by MCNP.

The distribution of the total neutron flux is shown in Fig. 6. Even though this is rough calculation, we might get reasonable flux distribution for generating importance map throughout the 30 concrete slabs.

With this result, we generate new importance for each cell and listed in Table II.

Table II: The generated new importance with rough AETIUS calculation

Cell ID	Zone average flux (rough AETIUS calculation)	New importance
201	7.36225E-05	1.00000E+00
202	5.32632E-05	1.38224E+00
203	3.12678E-05	2.35458E+00
204	1.70093E-05	4.32837E+00
205	8.70144E-06	8.46095E+00
206	4.22182E-06	1.74386E+01
207	1.95704E-06	3.76193E+01
208	8.81854E-07	8.34860E+01
209	3.86407E-07	1.90531E+02
210	1.65407E-07	4.45099E+02
211	7.02829E-08	1.04752E+03
212	2.92618E-08	2.51599E+03
213	1.22555E-08	6.00731E+03
214	5.02769E-09	1.46434E+04
215	2.05939E-09	3.57496E+04
216	8.42347E-10	8.74015E+04
217	3.42232E-10	2.15124E+05
218	1.38613E-10	5.31138E+05
219	5.61192E-11	1.31189E+06
220	2.23822E-11	3.28933E+06
221	8.93220E-12	8.24236E+06
222	3.58504E-12	2.05360E+07
223	1.42216E-12	5.17679E+07
224	5.59929E-13	1.31485E+08
225	2.21151E-13	3.32906E+08
226	8.64023E-14	8.52089E+08
227	3.38039E-14	2.17793E+09
228	1.32024E-14	5.57645E+09
229	5.06056E-15	1.45483E+10
230	1.39297E-15	5.28528E+10

With a new importance, we ran MCNP again and output is shown in Fig. 7. This time, we obtained slightly increasing tracks entering and this is much better than that of MCNP calculation with imp=1 for all cells.

As we can see in two MCNP results in Fig. 5 and 7, for too little splitting, the track population will decrease exponentially with increasing depth and no particles will ever penetrate the slab.

On the contrary, for too much splitting, the importance ratios are too large; the track population will increase exponentially and a particle history will never terminate.

For these reasons, a reasonably flat tracks entering distribution might be optimal, but it is not easy to have reasonably flat tracks entering distribution manually. If we do this manually, we may spend a lot of time to have it by doing trial and error.

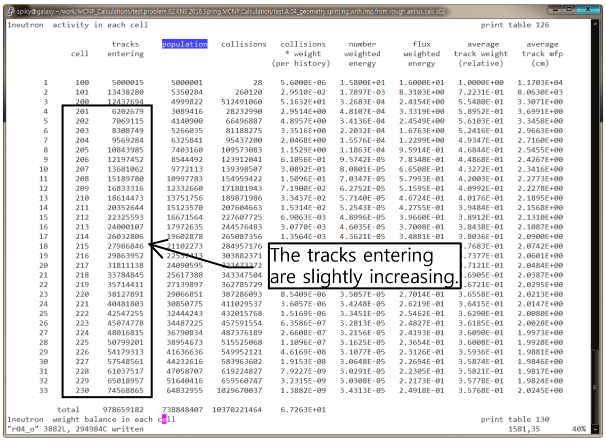

Fig. 7. The tracks entering result of MCNP calculation with generated new importance.

The cell average fluxes are compared in Fig. 8. AETIUS fine calculation is used as reference result. MCNP calculation with imp=1 for all cells gives large relative error in Fig. 9 and no tallies after 260cm in Fig. 8.

Even though the result of rough AETIUS calculation is different from the reference result, MCNP result with the importance map that generated based on the rough AETIUS calculation gives very good agreement with the reference result.

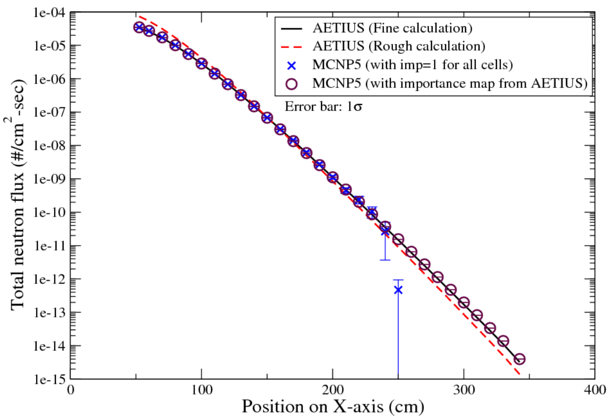

Fig. 8. Comparison of cell average fluxes (with 1σ error bar).

The relative errors of two MCNP runs are shown in Fig. 9. The relative errors of MCNP calculation with generated importance map are small enough to satisfy the MCNP guideline that "relative error should be less than 0.10 to produce generally reliable confidence intervals" [1]. However, the relative errors with imp=1 for all cells are getting increased up to 1.0. This is due to the tracks entering are getting decreased as depth is increased.

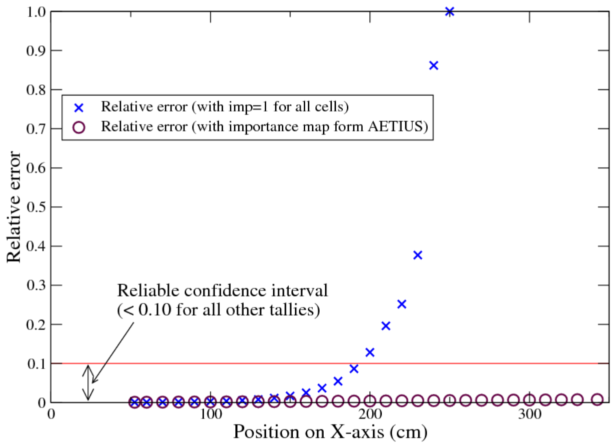

Fig. 9. Comparison of relative errors of two MCNP calculations.

3. Conclusions

We compared two MCNP results of the deep shielding problem. One is with imp=1 for all cells. The other is using importance map generated from AETIUS rough calculation.

The discretization of space, angle, and energy is not necessary for MCNP calculation. This is the big merit of MCNP code compared to the deterministic code. However, deterministic code (i.e., AETIUS) can provide a rough estimate of the flux throughout a problem relatively quickly. This can help MCNP by providing variance reduction parameters.

Recently, ADVANTG [10] code is released. This is an automated tool for generating variance reduction parameters for fixed-source continuous-energy Monte Carlo simulations with MCNP5 v1.60.

We are planning to add more functions to the AETIUS by benchmarking it for this application.

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